

**Tevatron Connection, August 9, 2004**

# Latest results EW and Top results from

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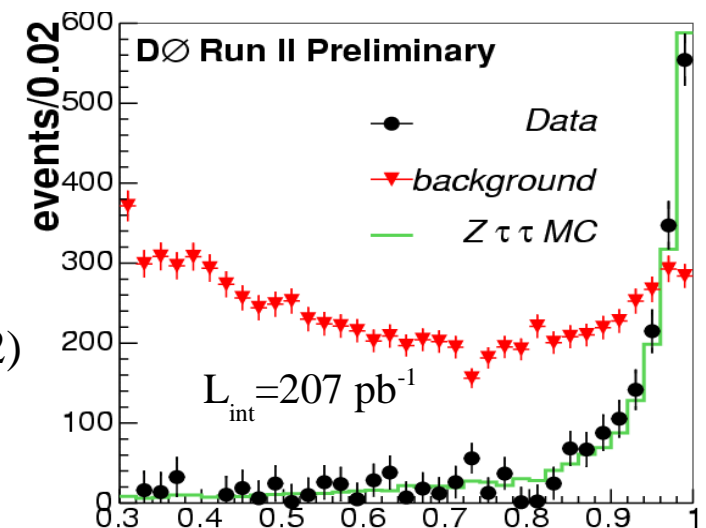
## Outline

- $Z \rightarrow \tau^+ \tau^-$  cross section
- WW cross section
- $Z\gamma$  cross section
- tt cross section in  $\ell$ +jets channel with b-tagging
- tt cross section in  $e\mu$ +jets channel with b-tagging
- Search for single top quark production
- Top mass measurement in  $\ell$ +jets channel
- W helicity measurement in top quark decays

# $Z \rightarrow \tau^+ \tau^-$ cross-section measurement



- Serves as benchmark **process** to test  $\tau$  identification
- Foundation for many analysis involving taus.
- Select events with one  $\tau \rightarrow \mu \nu \nu$ , other  $\tau$  decaying hadronically. Require opposite charges.
- Reconstruct 3 types of hadronic  $\tau$ :
  - type 1 ( $\pi \nu$ -like) - calorimeter cluster with single matched track. No EM subcluster
  - type 2 ( $\rho \nu$ -like) - calorimeter cluster with single matched track. With  $\geq 1$  EM subcluster
  - type 3 (3-prong) -  $\geq 2$  tracks matched with calorimeter cluster, consistent with  $\tau$  mass
- Construct Neural Network separately for all 3 types of hadronic  $\tau$ . Most input variables are ratios of energies to minimize dependence on  $E_\tau$ .
- Some selection cuts:
  - Isolated muon with  $P_T > 12$  GeV
  - Highest  $P_T$  track of hadronic  $\tau > 3.5$  GeV;
  - Hadronic  $\tau$   $E_T > 10$  GeV ( $> 5$  GeV) for type 1 & 3 (type 2)
  - Sum of track  $P_T > 7$  GeV ( $> 5$  GeV) for type 1 & 3 (type 2)
  - $|\Delta\phi| > 2.5$
  - $NN > 0.8$
- **1946 events** selected with  $\sim 55\%$  of background from  $bb$ ,  $W$ +jets, and  $Z \rightarrow \mu\mu$ , all estimated from data

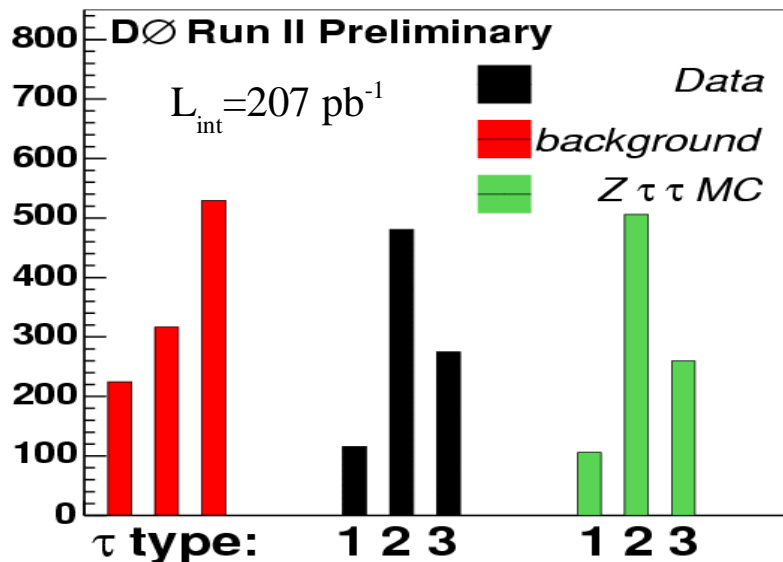
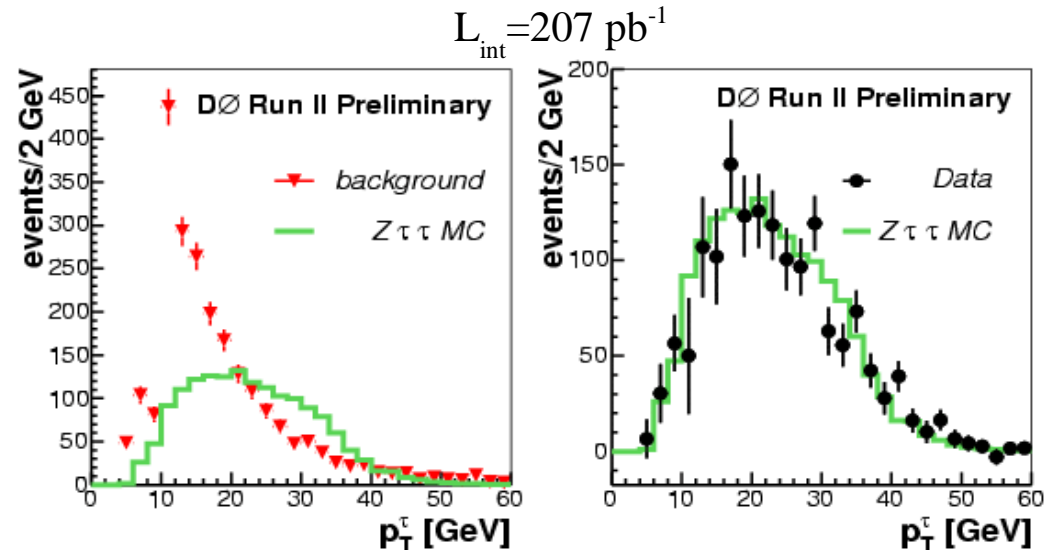


# $Z \rightarrow \tau^+ \tau^-$ cross-section measurement



- Efficiencies for 3 types of  $\tau$  (including  $\tau$  decay branchings)

- Type 1: 0.35%
- Type 2: 1.61%
- Type 3: 0.79%



$$\sigma(Z/\gamma^* \rightarrow \tau\tau) = 256 \pm 16(\text{stat}) \pm 17(\text{sys}) \pm 16(\text{lumi}) \text{ pb}$$

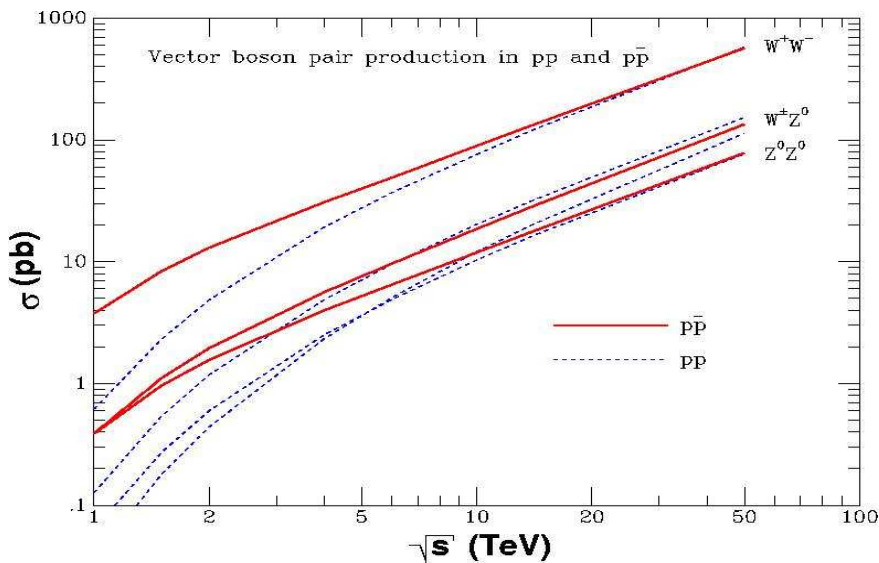
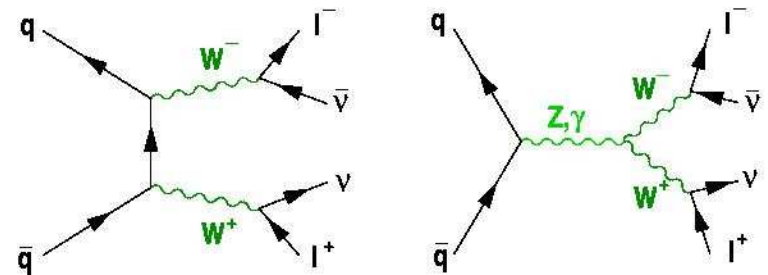
- Good agreement with the prediction.
- Systematics due trigger, data/MC correction factors, energy scale, NN, background estimate

# Measurement of the WW cross section



- Important measurement because

- WW production is major background for searches (Higgs, SUSY)
- It provides test of trilinear couplings (WWZ, WW $\gamma$ )



- Theoretical prediction (Campbell, Ellis)

- $\sigma(WW) = 13.5 \text{ pb @ } 1.96 \text{ TeV}$

- Main backgrounds

- Z/ $\gamma$ , tt, WZ, ZZ, W+jet/ $\gamma$ , multijets

- Data up to March 2004

- Integrated luminosity 224-252  $\text{pb}^{-1}$

- Selection criteria

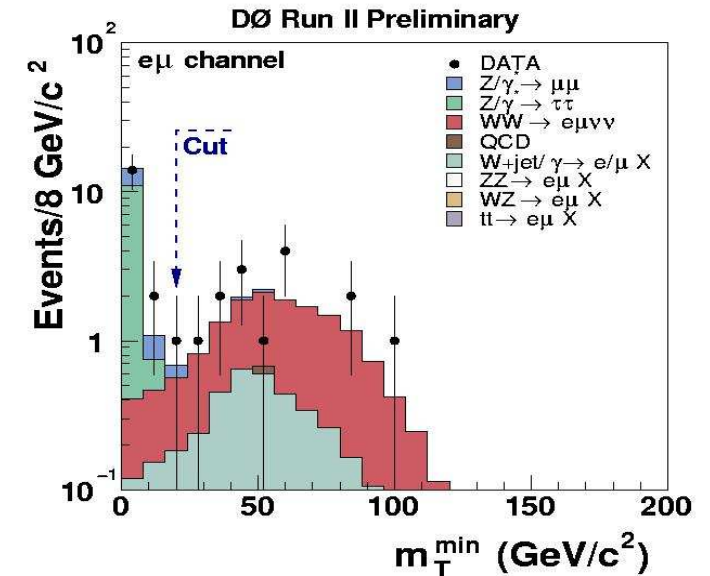
- Two high  $p_T$  leptons of opposite charge, large missing  $E_T$
- Veto on Z and jet events, suppress conversions

# Measurement of the WW cross section



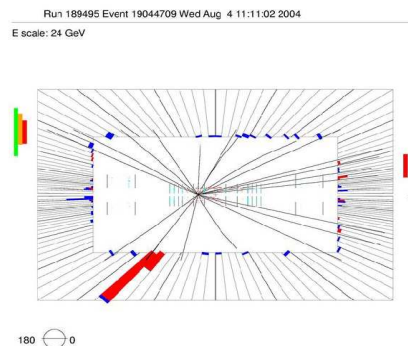
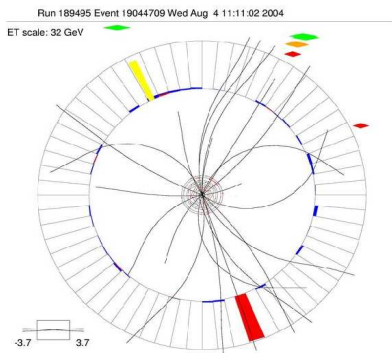
## Signal, background and data after final selection

Process	$ee$	$e\mu$	$\mu\mu$
WW signal	$3.26 \pm 0.05$	$10.8 \pm 0.1$	$2.01 \pm 0.05$
$Z/\gamma^* \rightarrow ee$	$0.20 \pm 0.06$	—	—
$Z/\gamma^* \rightarrow \mu\mu$	—	$0.28 \pm 0.09$	$1.6 \pm 0.4$
$Z/\gamma^* \rightarrow \tau\tau$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$t\bar{t}$	$0.18 \pm 0.02$	$0.34 \pm 0.03$	$0.09 \pm 0.01$
WZ	$0.33 \pm 0.17$	$0.38 \pm 0.02$	$0.15 \pm 0.08$
ZZ	$0.19 \pm 0.06$	$0.02 \pm 0.02$	$0.10 \pm 0.04$
$W + jet/\gamma$	$1.25 \pm 0.07$	$2.72 \pm 0.07$	$0.01 \pm 0.01$
QCD	$0.0 \pm 0.0$	$0.07 \pm 0.07$	$0.0 \pm 0.0$
Background sum	$2.30 \pm 0.21$	$3.81 \pm 0.17$	$1.94 \pm 0.41$
Data	6	15	4



## Combination of all three channels yields WW production cross section of

$$\sigma(WW) = 1.38^{+4.2}_{-3.8} (stat)^{+1.0}_{-0.8} (sys) \pm 0.9 (limi) pb$$



## Background probability

$$1 - CL_B = 2.3 \times 10^{-7}$$

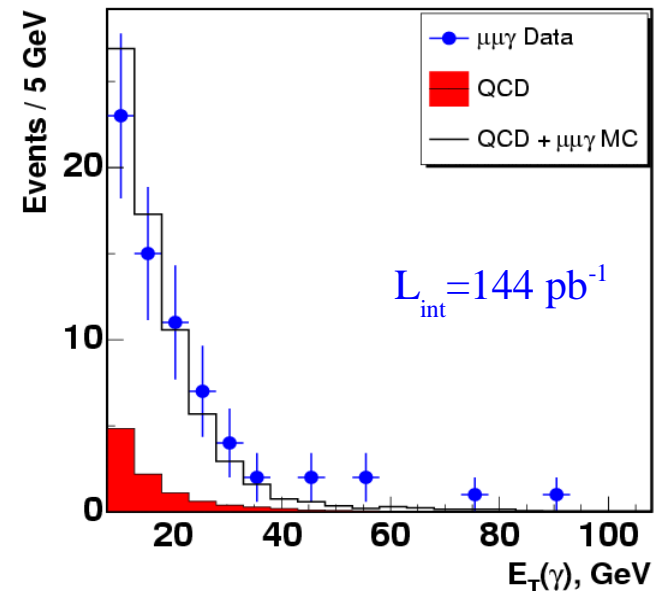
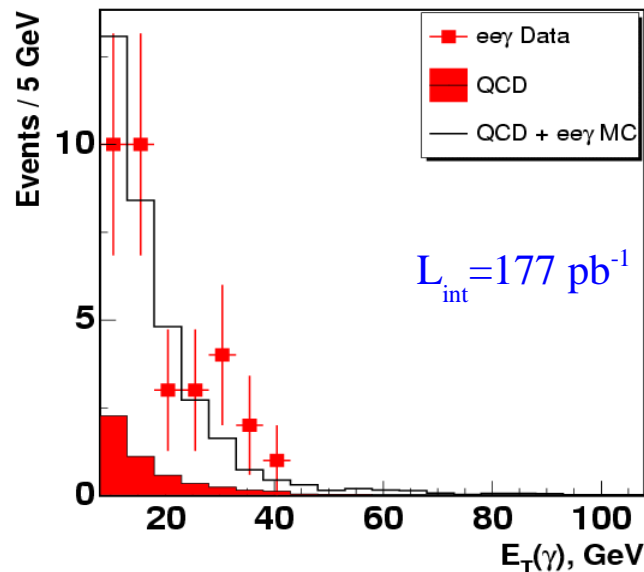
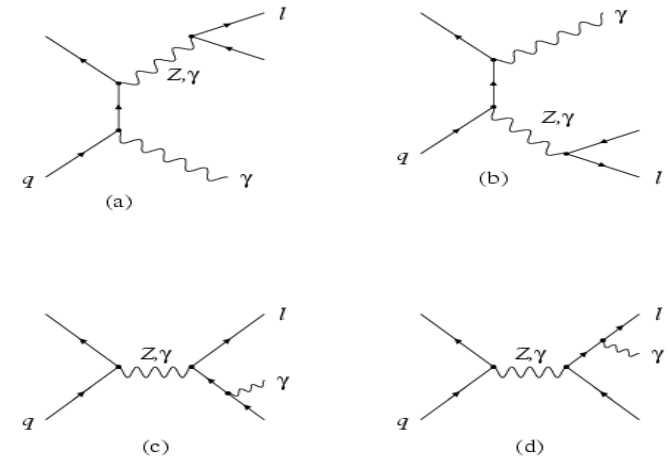
## Signal significance

$$5.2 \sigma$$

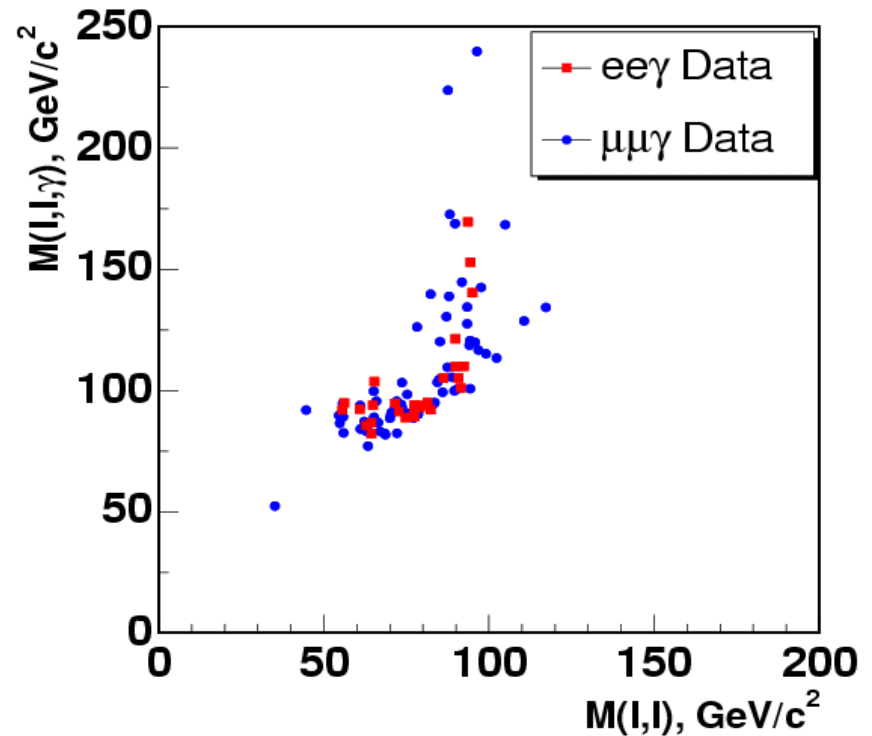
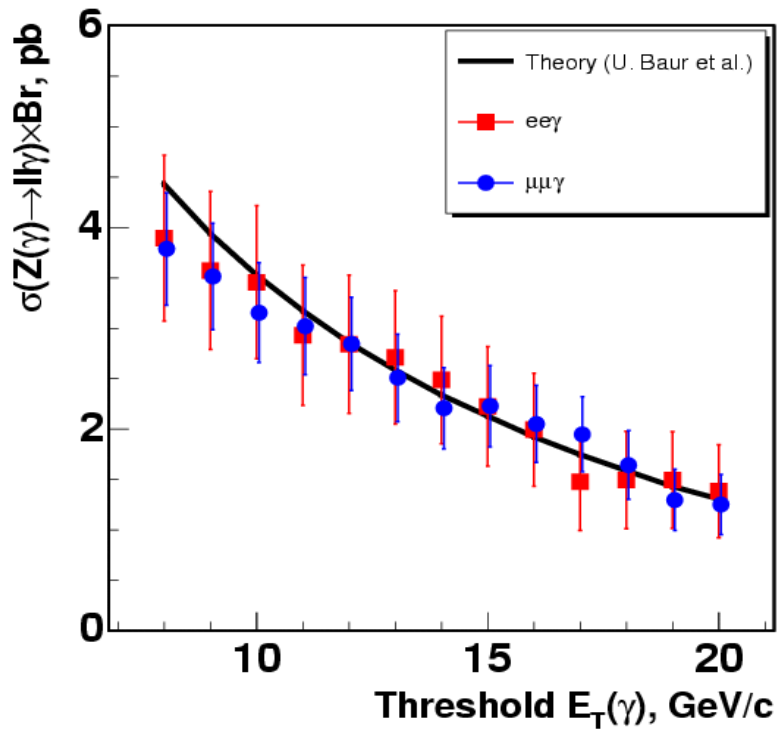
# $Z\gamma$ production cross-section



- Tool to probe trilinear gauge boson couplings,  $ZZ\gamma$  and  $Z\gamma\gamma$ .
- Requires efficient photon identification
- Event selection
  - Pair of high  $P_T$  isolated electrons or muons
  - $M(\ell^+\ell^-) > 30$  GeV
  - Isolated photon with  $P_T > 8$  GeV and with  $dR(\gamma, \ell) > 0.7$
  - Photon ID efficiency  $\approx 82 \pm 2$  %
- Signal events generated using MC by U. Baur.
- Main background is Z+jets production. Estimated from data.



# $Z\gamma$ production cross-section



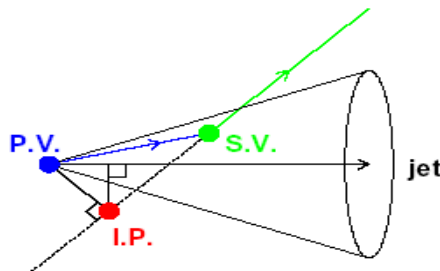
$$\sigma((Z\gamma)^* \rightarrow \mu\mu/ee, M_{\ell\ell} > 30 \text{ GeV}, P_T(\gamma) > 8 \text{ GeV}) = 3.99 \pm 0.8(\text{stat}) \pm 0.25(\text{sys}) \pm 0.26(\text{lumi}) \text{ pb}$$



# tt cross-section in the $\ell$ +jets channel using b-tagging

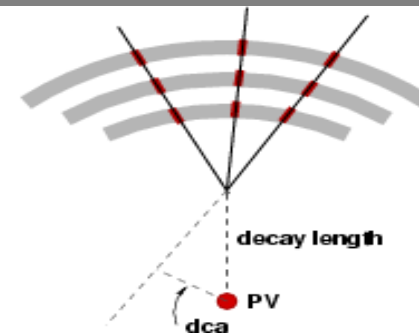
- Lepton + jets signature comes from  $tt \rightarrow W^+bW^-b \rightarrow \ell\nu b+qq'b$  decays. Similar signatures arise from **W+jets** and **QCD multijet** events.
- Basic kinematic cuts:
  - Isolated electron or muon with  $P_T > 20$  GeV
  - Missing  $E_T > 20(17)$  GeV for e+jets ( $\mu$ +jets); not aligned with lepton
  - At least 3 jets with  $P_T > 15$  GeV in  $|\eta| < 2.5$
- b-tagging requirement
  - At least one b-tagged jet
  - Treat separately samples with **exactly 1 b-tag** and  **$\geq 2$ -b-tag jets**
- Tagging algorithms
  - Two independent analysis applying different tagging techniques

## Counting Signed Impact Parameter (CSIP)



Jet is tagged if  
 $N_{tr}(\sigma_{IP} > 2) > 3$  OR  $N_{tr}(\sigma_{IP} > 3) > 2$

## Secondary Vertex Tagging (SVT)



Reconstructs displaced vertices. Cuts on vertex decay length significance

# $t\bar{t}$ cross-section in the $\ell$ +jets channel using b-tagging



- **Jet b-tagging efficiency in data:**
  - ➔ For b-jets tagging efficiency is obtained using jets containing muon
  - ➔ For light-quark/gluon jets tagging efficiency is determined from jets with negative decay length
- Obtained tagging parametrizations  $\epsilon_{\text{tag}}(E_T, \eta)$  are applied to  $t\bar{t}$  MC events to estimate overall signal tagging efficiency
  - $\epsilon_{1\text{-tag}}(t\bar{t}) \approx 45 \%$
  - $\epsilon_{\geq 2\text{ tag}}(t\bar{t}) \approx 12 \%$
- **The average b-tagging( $\geq 1\text{tag}$ ) probability for QCD multijets events is**
  - $\epsilon_{3\text{-jet events}}(t\bar{t}) \approx 4 \%$
  - $\epsilon_{3\text{-jet events}}(t\bar{t}) \approx 5 \%$
- **Backgrounds**
  - QCD background obtained entirely from data.
  - Relative composition of W+jets background is taken from ALPGEN MC. This together with b-tagging efficiency parametrizations gives overall W+jets tagging efficiency. Number of untagged W+jets events comes from data.

# tt cross-section in the $\ell$ +jets channel using b-tagging



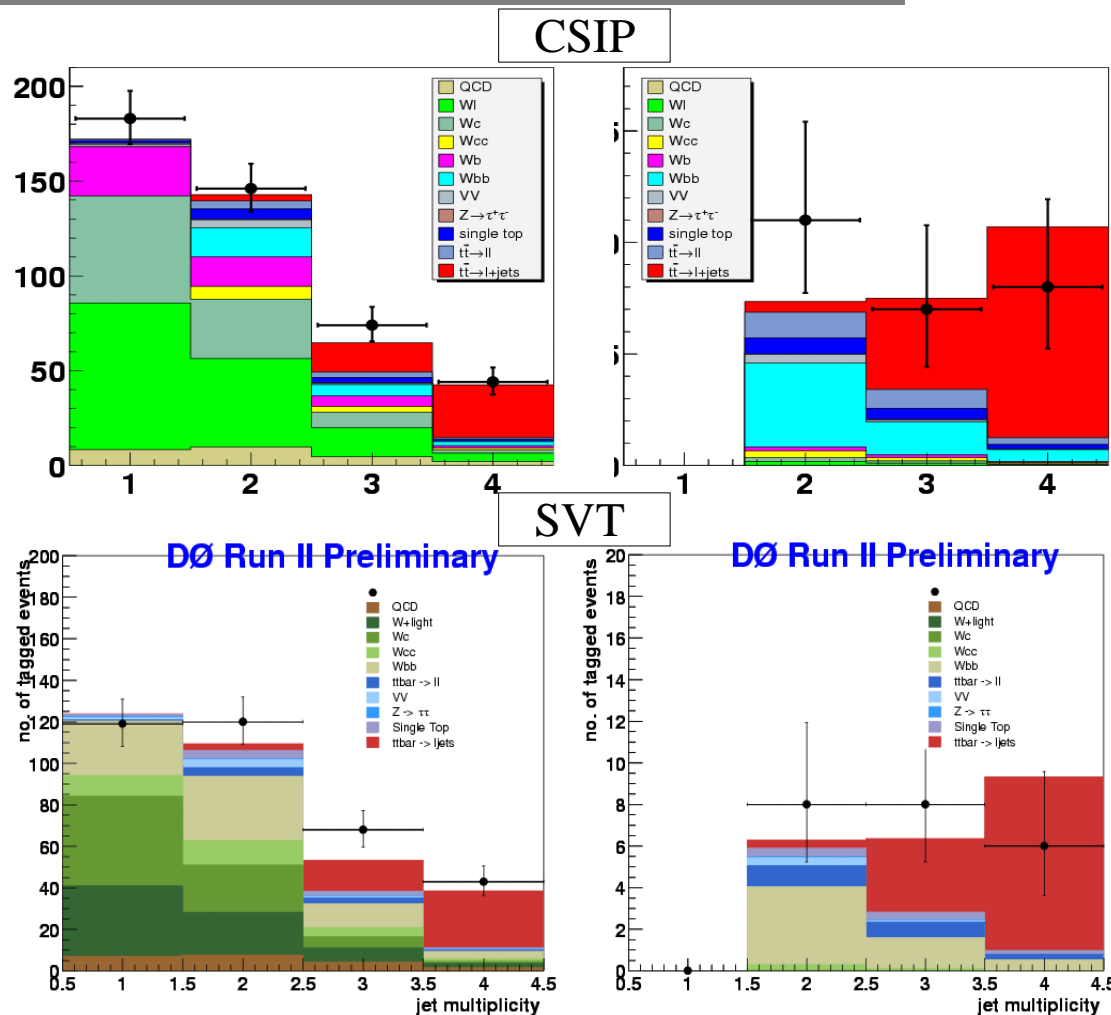
## Number of events

	W+1jet	W+2jets	W+3jets	W+ $\geq$ 4jets
preselected	6321	2348	586	174
CSIP: tagged	103	87	43	34
double tagged		6	4	5
SVT: tagged	64	69	34	33
double tagged		4	5	3

$e+jets: 168.8 \text{ pb}^{-1}$

	W+1jet	W+2jets	W+3jets	W+ $\geq$ 4jets
preselected	5130	2077	511	119
CSIP: tagged	80	70	38	18
double tagged		5	3	3
SVT: tagged	55	59	42	16
double tagged		4	3	3

$\mu+jets: 158.4 \text{ pb}^{-1}$



- Combine  $(=1\text{jet}, \geq 2\text{jets}) \times (1\text{b-tag}, \geq 2\text{ b-tags}) \times (e+jets, \mu+jets)$  channels

CSIP

$$\sigma(tt) = 7.18_{-1.19}^{+1.28} (stat)_{-1.38}^{+1.93} (sys) \pm 0.47 (lumi) \text{ pb}$$

SVT

$$\sigma(tt) = 8.24_{-1.25}^{+1.34} (stat)_{-1.63}^{+1.89} (sys) \pm 0.54 (lumi) \text{ pb}$$

# $t\bar{t}$ cross-section in the $e\mu$ +jets channel using b-tagging

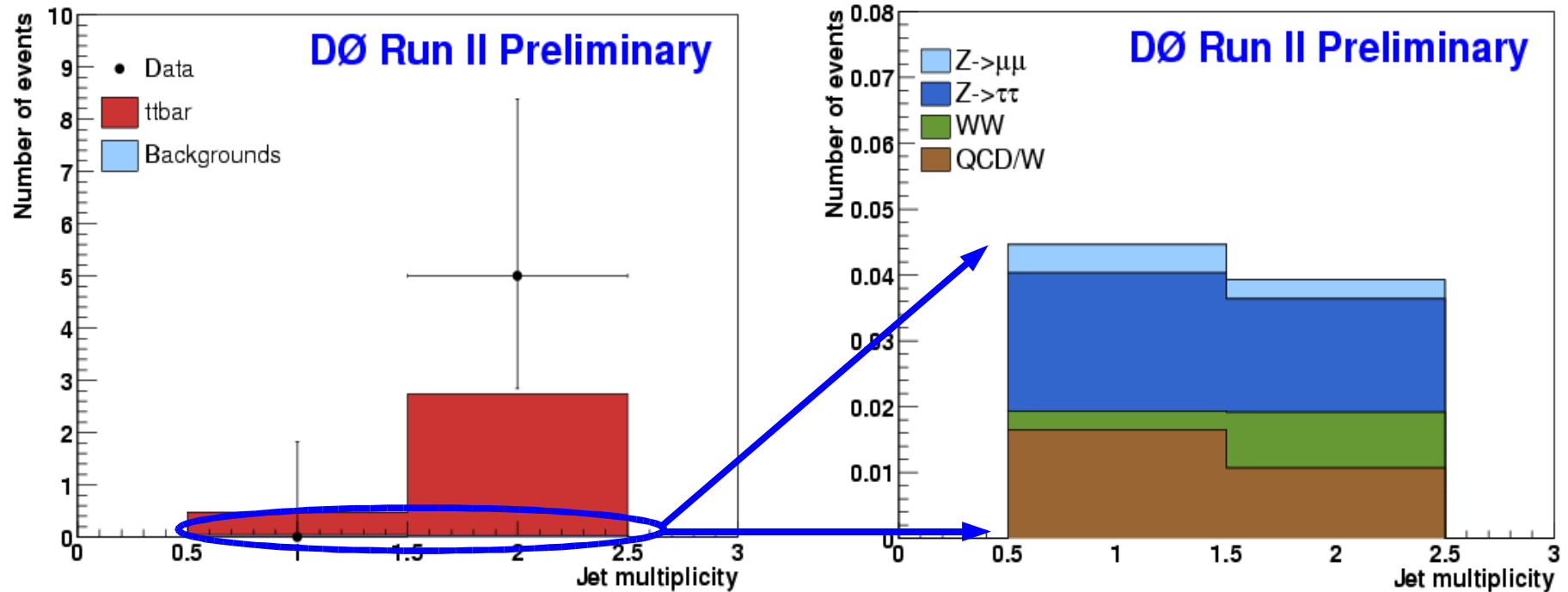


- $e\mu$  + jets is the cleanest  $t\bar{t}$  channel.  
Applying additional b-tagging requirement makes it essentially background free.
- **Event selection**
  - Isolated electron and muon with  $P_T > 15$  GeV
  - Missing  $E_T > 25$  GeV
  - At least one jet with  $P_T > 15$  GeV
  - At least one jet tagged by Secondary Vertex Tagger
- **Signal b-tagging efficiency estimated using per-jet b-tagging efficiency parametrizations obtained in data**
  - $\epsilon(t\bar{t}) = 38\%$  for  $e\mu + 1$  jet events
  - $\epsilon(t\bar{t}) = 59\%$  for  $e\mu + \geq 2$  jets events
- **Main backgrounds**
  - Physics background:  $Z(\rightarrow\tau\tau) + \text{jet(s)}$
  - Instrumental background: QCD multijet,  $W$ +jets

# $t\bar{t}$ cross-section in the $e\mu$ +jets channel using b-tagging



$L_{\text{int}} = 158 \text{ pb}^{-1}$



- Cross-section obtained by combining  $=1\text{jet}$  and  $\geq 2\text{jets}$  bins

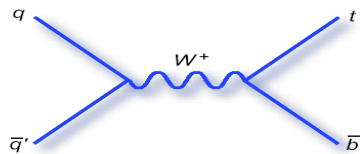
$$\sigma(tt) = 11.1^{+5.8}_{-4.3} (stat) \pm 1.4 (sys) \pm 0.7 (lumi) pb$$

# Search for single top quark production



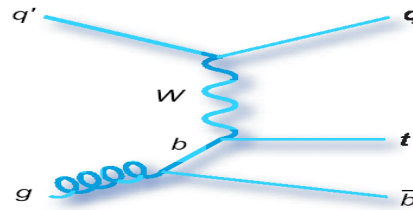
## Two main production mechanisms at the Tevatron

s-channel



$$\sigma^{\text{NLO}} = 0.88 \text{ pb}$$

t-channel



$$\sigma^{\text{NLO}} = 1.98 \text{ pb}$$

→ Measure CKM element  $V_{tb}$

→ Observe top polarization

• Signature: high  $P_T$  lepton, large missing  $E_T$ ,  $\geq 2$  jets ( $\geq 1$  b-jet)

• Selection:

→ Isolated e or  $\mu$  with  $P_T > 15$  GeV

→  $1 < N_{\text{jets}} < 5$

→ Leading jet with  $P_T > 25$  GeV in  $|\eta| < 2.5$ ; Other jets with  $P_T > 15$  GeV in  $|\eta| < 3.4$

→  $15 \text{ GeV} < \text{Missing } E_T < 200 \text{ GeV}$

→  $H_T(\text{ME}_T + \text{lepton} + \text{jet1} + \text{jet2}) > 150 \text{ GeV}$

→ At least one jet tagged as a b-jet by **lifetime tagger** OR by **soft muon tagger (SLT)**

→ Two parallel analysis using two lifetime taggers:

→ **SVT** explicitly reconstructs secondary vertices

→ **JLIP** computes probability (based on  $\sigma_{\text{IP}}$ ) that track in jet come from the interaction point

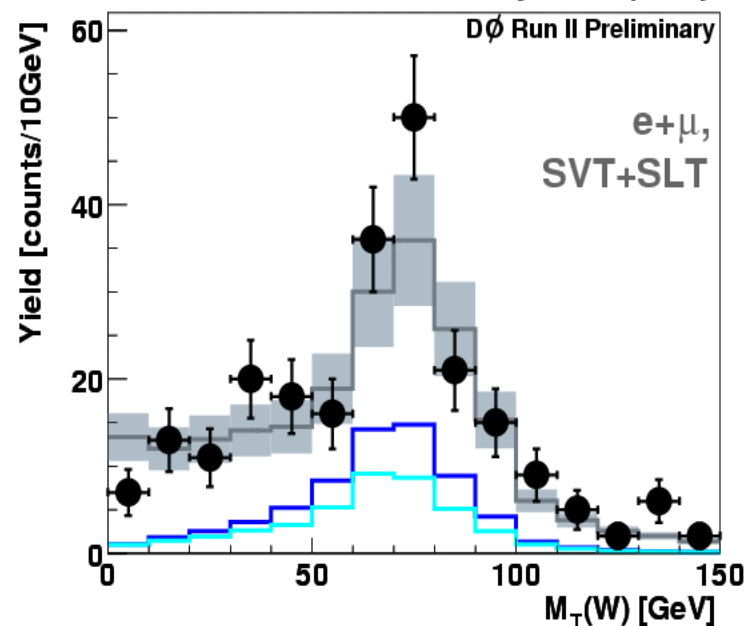
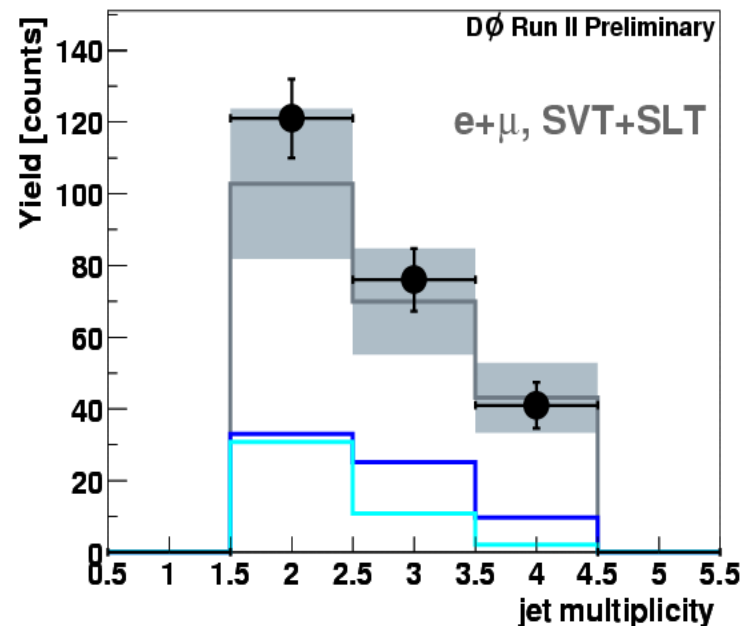
# Search for single top quark production



- Signal generated with CompHep+Pythia
- Main backgrounds: W+jets and QCD estimated from data;  $t\bar{t}$  estimated from MC;  $Z(\rightarrow \mu\mu) + \text{jets}$  estimated from data+MC
- Luminosities:  $145\text{-}169 \text{ pb}^{-1}$  for electron channel,  $158 \text{ pb}^{-1}$  for muon channel

<i>Electron+muon yield</i>	SLT	SVT	JLIP
Signals			
<i>s</i> -channel	$1.3 \pm 0.3$	$3.1 \pm 0.8$	$3.2 \pm 0.7$
<i>t</i> -channel	$1.7 \pm 0.4$	$5.1 \pm 1.3$	$5.3 \pm 1.3$
Backgrounds			
$t\bar{t}$	$17.8 \pm 4.1$	$43.2 \pm 10.4$	$43.7 \pm 10.9$
$W/Z + \text{jets} + \text{fake-}l$	$58.4 \pm 11.5$	$94.2 \pm 17.7$	$122.2 \pm 23.9$
Sum of backgrounds	$76 \pm 11$	$137 \pm 21$	$166 \pm 26$
Observed	97	138	148

$e+\mu$ , SLT + SVT	Observed/Expected Limit at 95% CL (pb)	
	Bayesian	Modified Frequentist
<i>s</i> - channel	19/16	17/16
<i>t</i> - channel	25/23	25/22
<i>s</i> - and <i>t</i> - channel	23/20	23/19



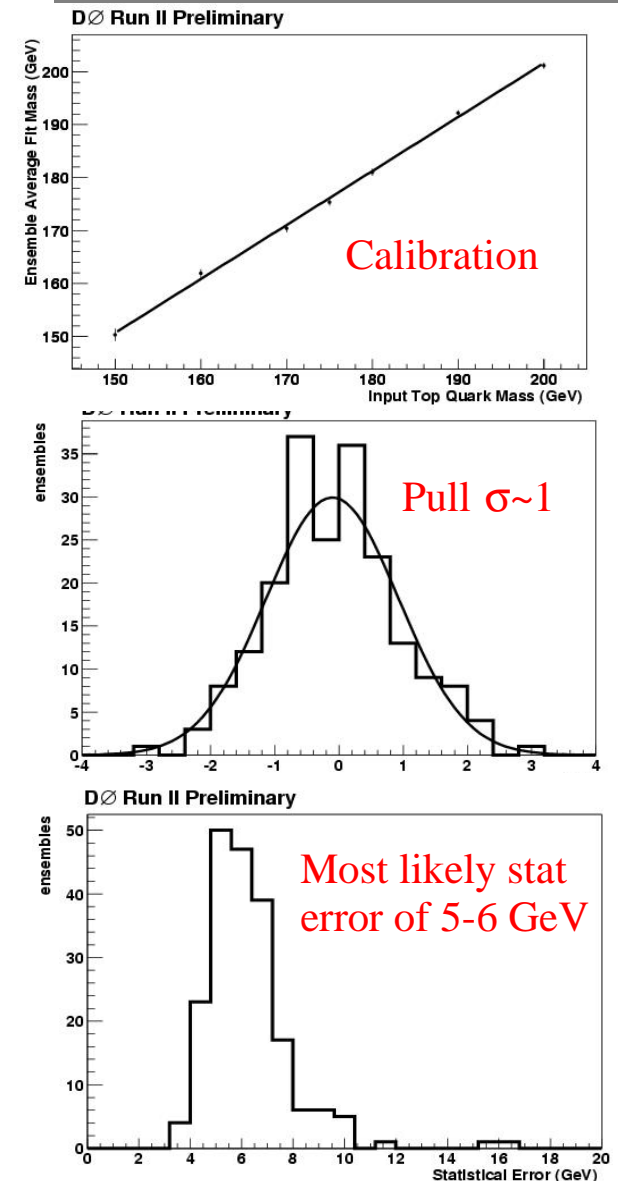
# Top mass in $\ell$ +jets channel : Template method



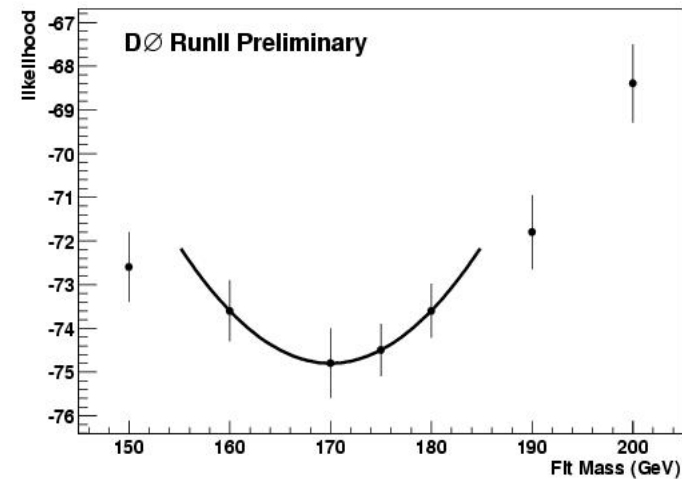
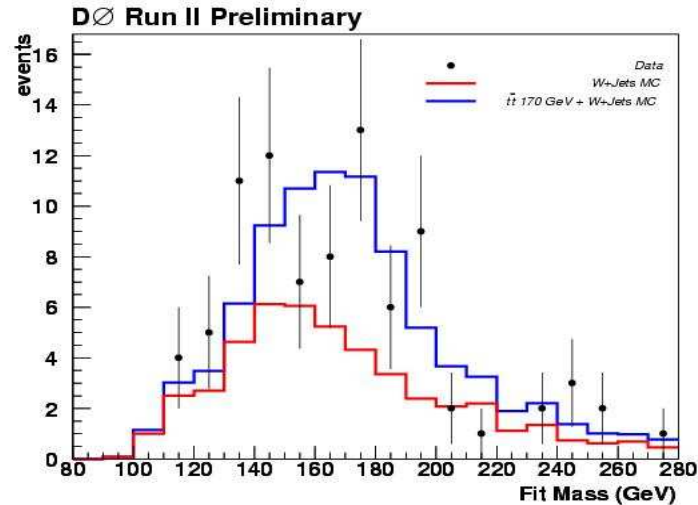
- $tt \rightarrow W^+bW^-b \rightarrow \ell\nu b + qq'b$  system is kinematically over-constrained
  - Use constraint fit to reconstruct top mass  $m_t$  for all 12 possible jet-lepton assignments.
  - Take  $m_t$  from permutation with lowest fit  $\chi^2$
- Build low bias discriminant  $D_{LB}$  using topological variables . Apply  $D_{LB} > 0.4$ .
- Fit observed  $m_t$  distribution to the templates of signal, W+jets (MC) and QCD (data) events
- Use binned likelihood fit. Constrain sample purity to the expectation through Poissonian probability term
- Composition of the sample before  $D_{LB} > 0.4$  cut:

$L_{int} \approx 160\text{pb}^{-1}$	$e+\text{jets}$	$\mu+\text{jets}$
no.of events selected in data	101	90
estimated sample composition:		
$tt$	30.9	29.9
$W + \text{jets}$	65.7	53.4
multijets	4.4	6.9

## The method performance

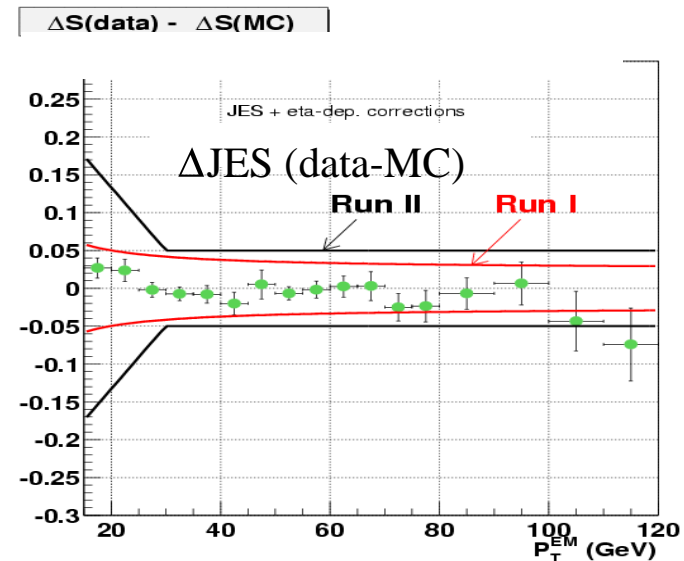


# Top mass in $\ell$ +jets channel : Template method



$$m_{top} = 170.0 \pm 6.5 (stat)^{+10.2}_{-6.5} (sys) GeV$$

- Measured mass changes from 170.0 to 172.1 when removing purity constraint
- Systematic uncertainty dominated by Jet Energy Scale error. Currently using conservative estimate



# Top mass in $\ell$ +jets channel: Ideogram Method



- Event-by-event likelihood taking into account all 24 jet+neutrino solutions from kinematic fit and probability that the event is background
- Event selection as Template method, without  $D > 0.4$
- Let overall signal fraction  $P_{\text{samp}}$  float freely in fit for each top mass  $m_t$

$$\mathcal{L}_{\text{evt}}(m_t, P_{\text{samp}}) =$$

$$P_{\text{evt}} \cdot \left[ \int_{100}^{300} \sum_{i=1}^{24} w_i \cdot \mathbf{G}(m_i, m', \sigma_i) \cdot \mathbf{BW}(m', m_t) dm' \right] + (1 - P_{\text{evt}}) \cdot \sum_{i=1}^{24} w_i \cdot \mathbf{BG}(m_i)$$

$$w_i = \exp\left(-\frac{1}{2}\chi_i^2\right)$$

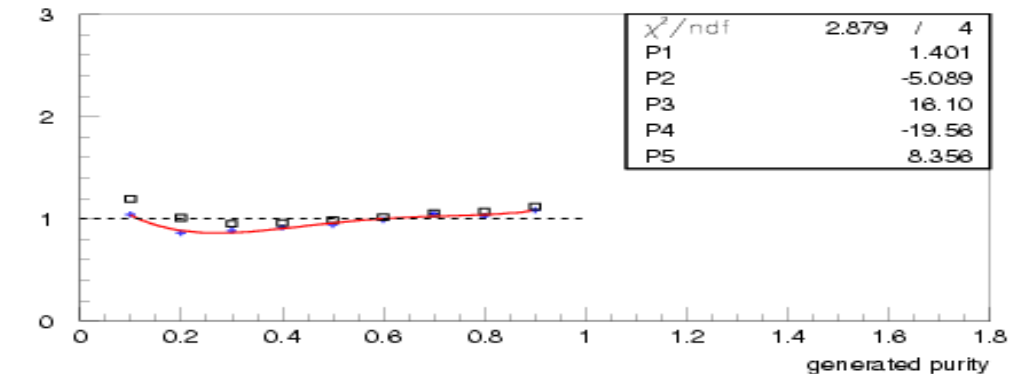
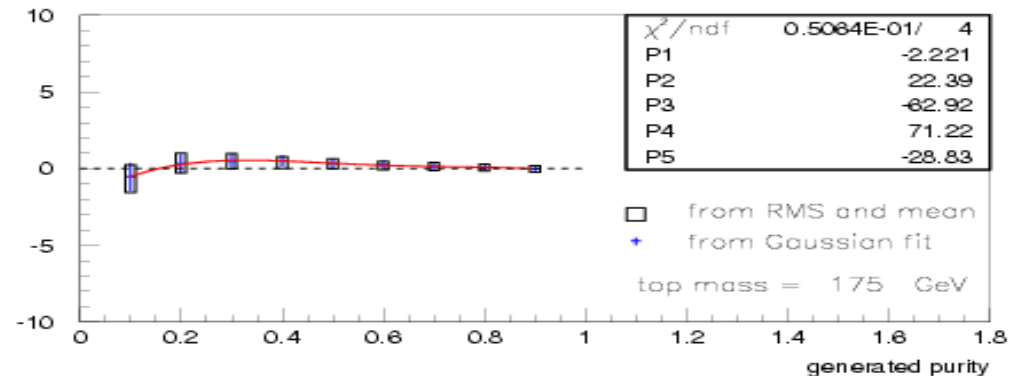
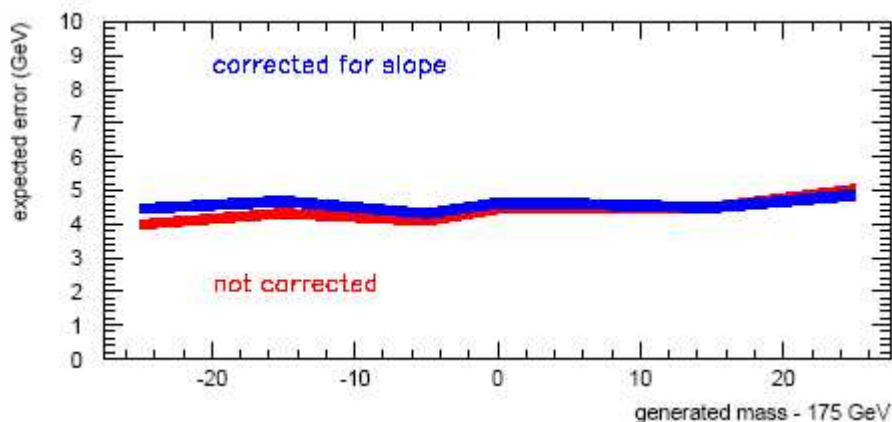
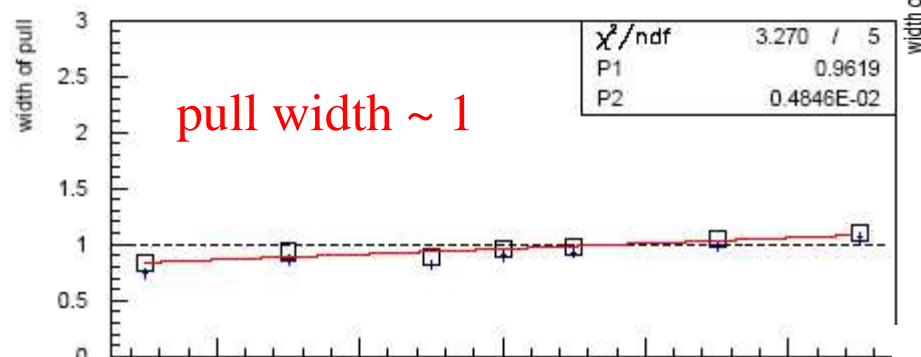
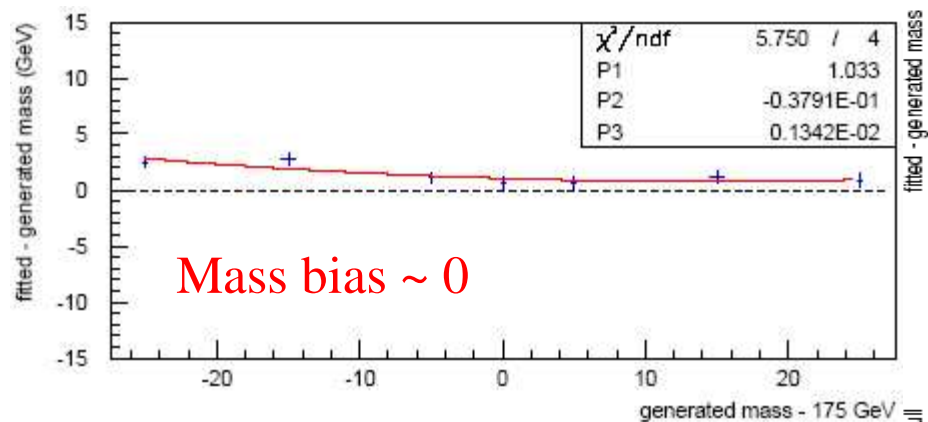
Uses all possible jet/neutrino combinations, best permutation has most weight

BG shape from MC

$$P_{\text{evt}} = \left( \frac{S}{S+B} \right)_{\text{evt}} = \frac{(S/B)_{\text{evt}}}{(S/B)_{\text{evt}} + 1} = \frac{(S/B)_{\text{samp}} \cdot (S/B)_D}{(S/B)_{\text{samp}} \cdot (S/B)_D + 1}$$

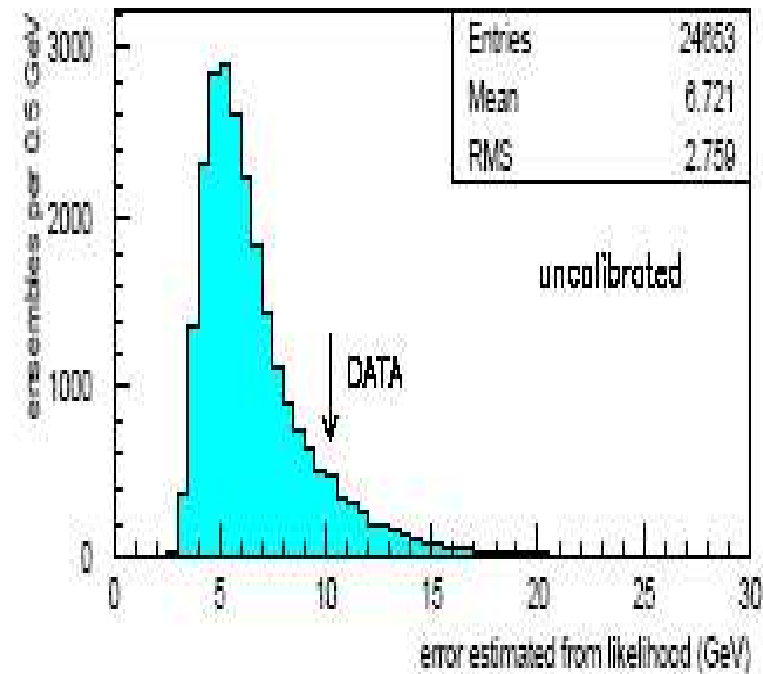
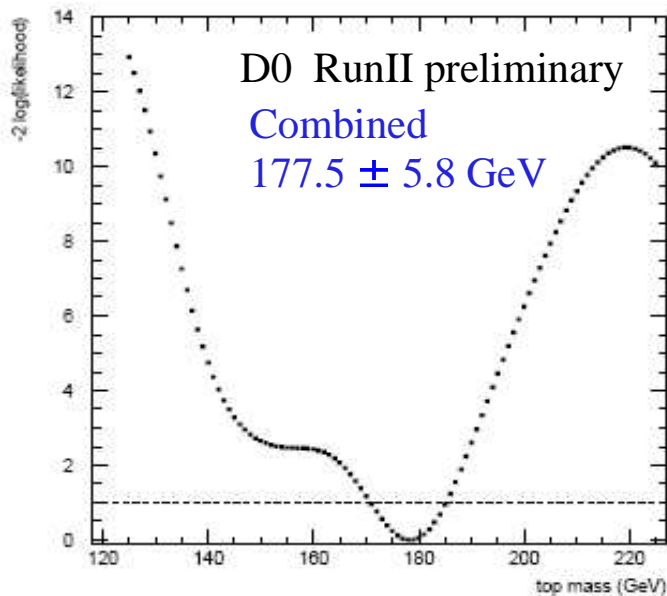
Weights each event by the topological discriminant so that the events that are most likely top count the most

# Top mass in $\ell$ +jets channel: Ideogram Method



Mass bias and width of the pull stable over whole mass range (150 – 200 GeV) and purity range (10 – 90%) tested

# Top mass in $\ell$ +jets channel: Ideogram Method



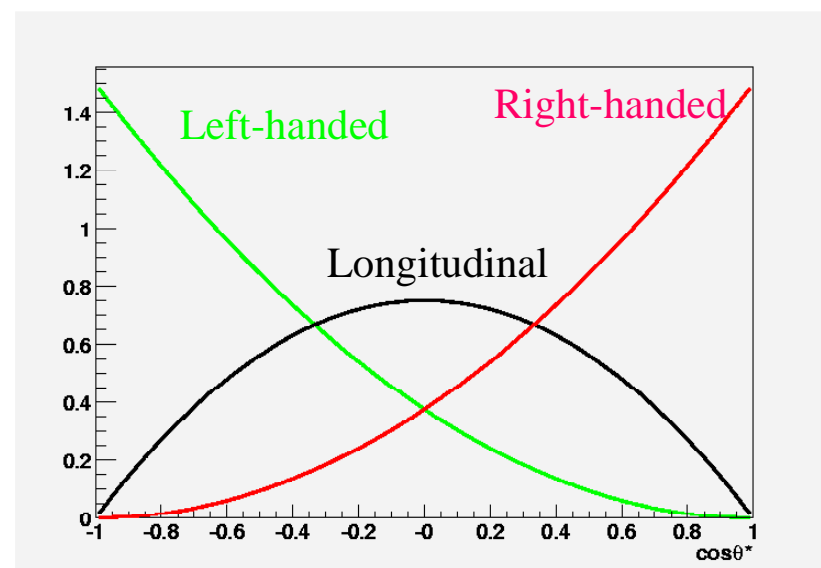
$$m_{top} = 177.5 \pm 5.8 (stat) \pm 7.2 (sys) pb$$

- Measured mass changes from 177.5 to 170.0 when applying purity constraint

# W helicity measurement in top quark decays



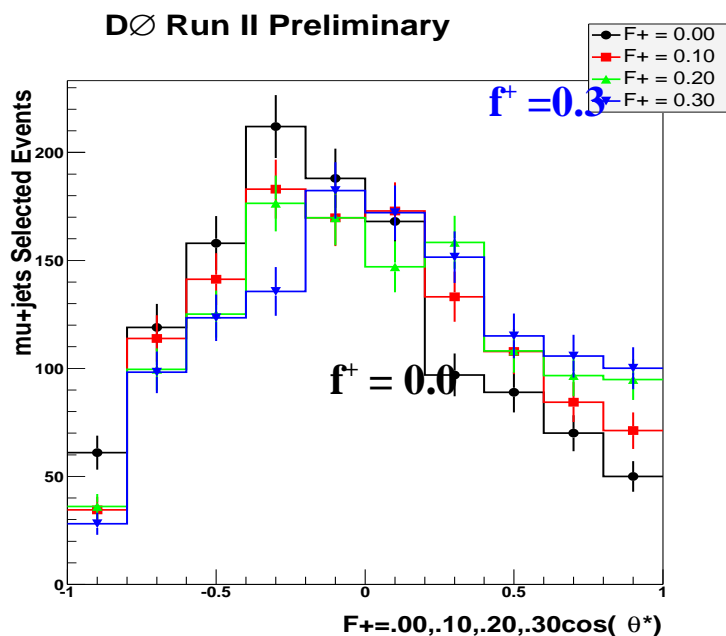
- In the Standard Model, W helicity depends only on top and W masses
  - Predicted to be 70% longitudinal, 30% left-handed, and 0% right-handed
  - We measure right-handed fraction  $f^+$
- Nonzero value would indicate
  - New physics at the  $tWb$  vertex
  - Source other than  $t\bar{t}$  contributing to signal
- W helicity determines the distribution of  $\cos\theta^*$ 
  - Angle between lepton and top directions in W rest frame
- Data up to November 2003
  - Integrated luminosity  $\sim 158 \text{ pb}^{-1}$
- Selection of muon+jets events
  - high- $p_T$  muon,  $\geq 4$  jets, missing  $E_T$
  - Two parallel analyses differing in further selection to reduce background
  - One uses purely topological information (topological analysis); other uses topological information, plus requires at least 1 jet tagged by SVT (b-tag analysis)



# W helicity measurement in top quark decays



- Number of events after selection in 'topological analysis':
  - 31 candidates observed in data
  - Expected yield for signal and background:  $\sim 11$  and  $\sim 20$  events, respectively
- Number of events after selection in 'b-tag analysis':
  - 12 candidates observed in data
  - Expected yield for signal and background:  $\sim 9.6$  and  $\sim 2.7$  events, respectively
- Ideal distributions in  $\cos\theta^*$  modified by event combinatorics, detector resolution, and selection:

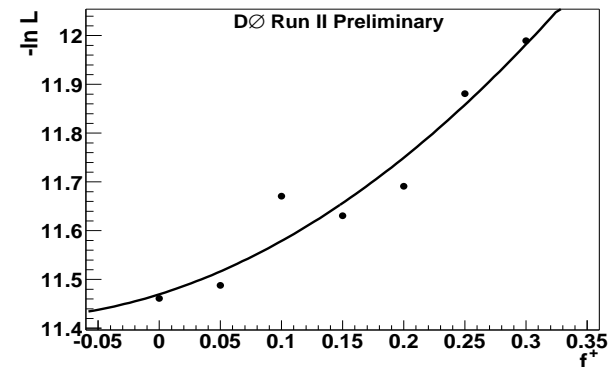
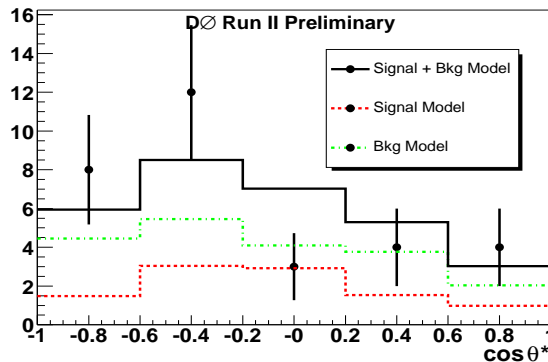


- Binned maximum likelihood fit used to extract  $f^+$ . inputs are:
  - $\cos\theta^*$  distribution in data
  - $\cos\theta^*$  distribution in sig and bkgd MC
  - Expected bkgd contribution
- MC tests confirm that fit result and errors are unbiased

# W helicity measurement in top quark decays

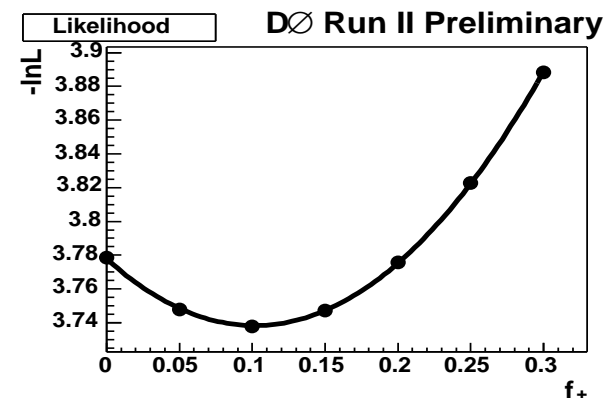
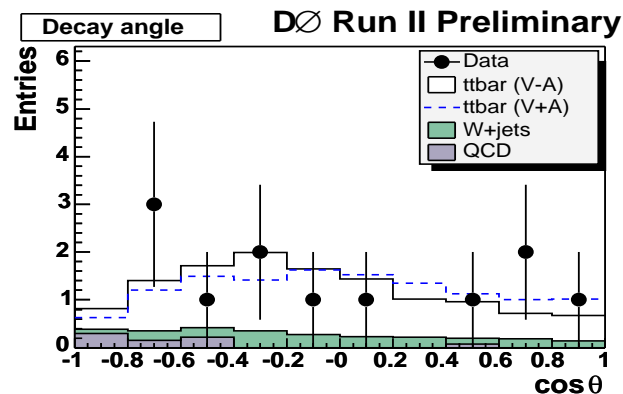


- Result of the topological analysis:



Bayesian upper limit:  $f^+ < 0.261$  @ 90% C.L.

- Result of the b-tag analysis:



Bayesian upper limit:  $f^+ < 0.269$  @ 90% C.L.

- Systematics include jet energy scale, top quark mass, signal and background MC models

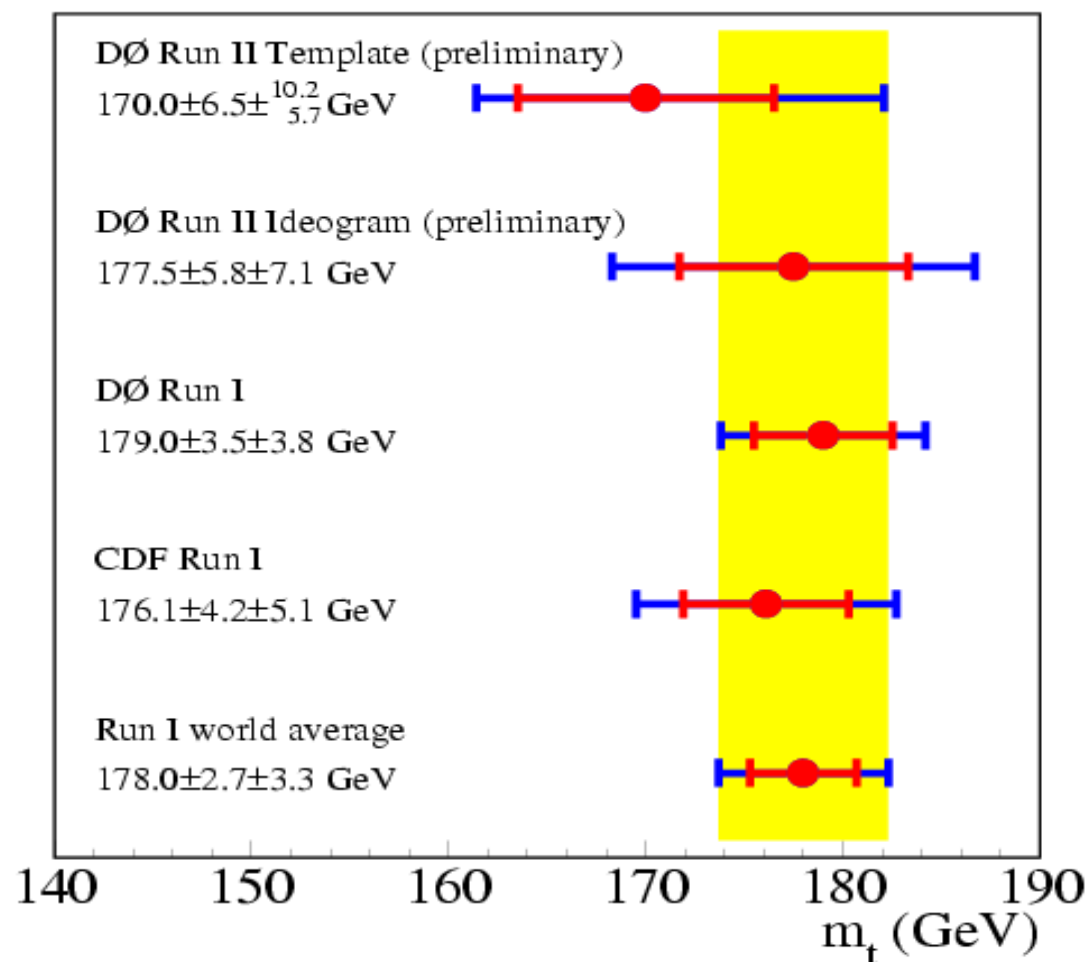
# Summary



- Many new exciting results from Dzero.  
I could only cover some of them .
- Many more to come

Backup slides

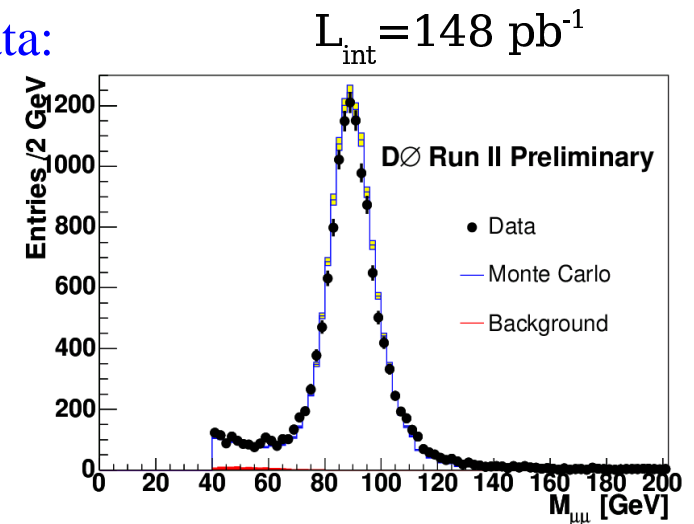
# Top mass in $\ell$ +jets channel: Summary



# $Z \rightarrow \mu^+ \mu^-$ cross-section measurement



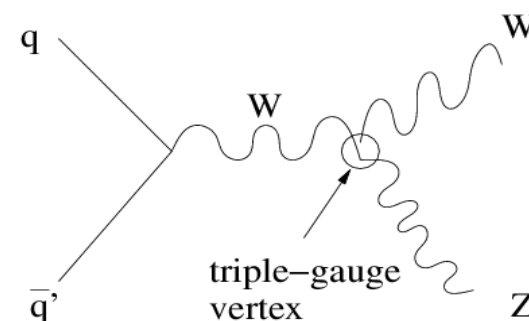
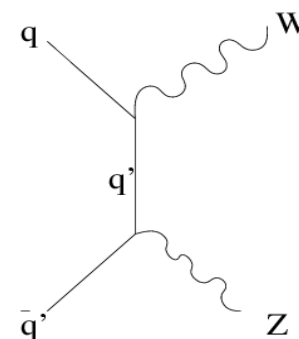
- Provides indirect measurement of **W width** when combined with  $\sigma(W)$ .
- Serves as **benchmark process** to test detector performance
- Standard tool to measure lepton identification, isolation and tracking efficiencies.
- Event selection:
  - Two oppositely charged isolated muons with  $P_T > 15$  GeV in  $|\eta| < 2$
  - $M_{\mu\mu} > 30$  GeV
- Small background ( $\sim 1.3\%$ ), mostly determined from data:
  - $bb$  (0.5%)
  - $Z \rightarrow \tau^+ \tau^-$  (0.5%)
  - **Cosmic muons (0.1%)**
  - **$W \rightarrow \mu\nu + \text{jets}$  (0.2%)**
- Signal efficiency 22-32% (different run periods)
- **Obtained cross-section:**  
$$\sigma((Z/\gamma)^* \rightarrow \mu\mu, M_{(Z/\gamma)^*} > 30 \text{ GeV}) = 329.2 \pm 3.4(\text{stat}) \pm 7.8(\text{sys}) \pm 21.4(\text{lumi}) \text{ pb}$$
- **Correct for pure photon and  $(Z/\gamma)^*$  interference – factor of  $0.885 \pm 0.013$  obtained from MCatNLO**  
$$\sigma(Z \rightarrow \mu\mu) = 291.3 \pm 3.0(\text{stat}) \pm 6.9(\text{sys}) \pm 18.9(\text{lumi}) \text{ pb}$$



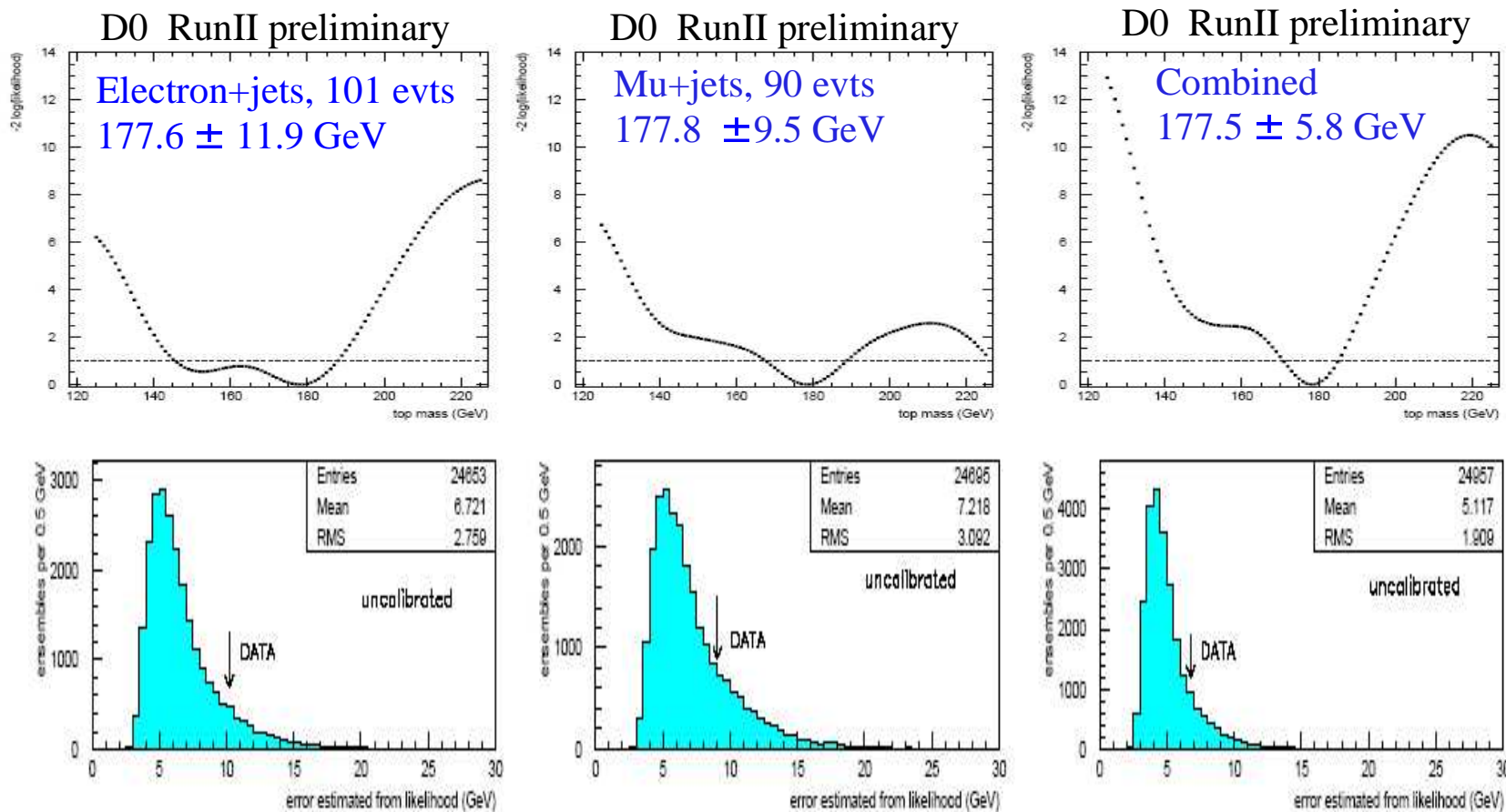
# $WZ \rightarrow \ell \ell \ell$ production



- Small cross-section,  $\sigma=3.7$  pb
- But very distinctive signature
- Test of SM via triple-gauge boson coupling
- Event selection:
  - Three isolated leptons ( $\ell = e, \mu$ ) with  $P_T > 15$  GeV
  - Missing  $E_T > 20$  GeV
  - $dR(\ell, \ell) > 0.2$
  - Z mass window cut
  - $M_T > 50$  GeV
- Main background is Z+jets production. Estimated from data.
- Analyzed dataset:  $L_{\text{int}} = 138\text{-}171$  pb<sup>-1</sup>
- Expected total number of events: 1.02 signal and 0.38 background
- 1  $\mu\mu\mu$  candidate observed in data
- Cross-section limit:  
 $\sigma(WZ) < 15.1$  pb @ 95% C.L.



# Top mass in $\ell$ +jets channel: Ideogram Method



Systematic uncertainty again dominated by Jet Energy Scale error